VŠB – Technical University of Ostrava
Faculty of Mechanical Engineering
Department of Robotics

Construction of Effecter for Sampling Liquid

Konstrukce efektoru pro odběr vzorků kapalin.

Student: Michal Gloger
Supervisor: Professor Pasi Kallio, Ph.D
Ing. Jan Burkovič, Ph.D

Ostrava 2009

VYSOKÁ ŠKOLA BÁŇSKÁ – TECHNICKÁ UNIVERZITA OSTRAVA
FAKULTA STROJNÍ

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

Konstrukce efektoru pro odběr vzorků kapalin

Construction of Effector for Sampling Liquid

Student:	Michal Gloger
Studijní obor:	2301R013-70 Robotika
Pracoviště:	Katedra robototechniky – 354

Zásady pro zpracování:

1. Proveďte analýzu současného stavu provádění odběru vzorků kapalin.

2. Navrhněte konstrukci efektoru servisního robotu, kterým budou prováděny odběry vzorků kapalin po chemickém, biologickém případně i jaderném zásahu! Součástí řešení bude i bezpečné uložení odebraných vzorků a jejich transport k laboratorní analýze.

3. Posuďte navržené varianty a zpracujte konstrukční návrh vybrané varianty do úrovně sestavných výkresů.

4. Vypracujte technickou zprávu s potřebnými výpočty.

5. Zhodnoťte dosažené výsledky.

6. Práci též doložte v elektronické podobě ve formátu editoru MSWORD a konstrukční řešeni v CAD systému (podle pokynů vedoucího).

Pokyny pro zpracování:

Rozsah práce: min. 30 stran textu mimo přílohy

Seznam doporučené literatury:

CHURÁČEK, J. *Analytická separace látek.* 1. vyd. Praha: SNTL Praha, 1990. 384 s. ISBN 80-30-00569-8.

ČAPOUN, T. a kol. *Havárie s únikem nebezpečných látek a protichemická opatření – učební texty.* 1. vydání. Lázně Bohdaneč: ICO ČR, 1999. 230 s.

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CHURÁČEK, J. aj. *Analytická toxikologie – skriptum.* Pardubice: VŠCHT, 1983.
Jednotná metodika odběru a úpravy vzorků [rezortní předpis CO-3-7]. Praha: FMNO, 1988.

TUŠÁROVÁ, I. - UCHYTIL, B. - ČAPOUN, T. *Analýza vysoce toxických látek ve stacionárních laboratořích CO: Odběr a úprava vzorků.* 1. vydání. Praha: MNO, 1983. 49 s.

Vedoucí bakalářské práce:	Ing. Jan Burkovič, Ph.D.
Datum zadání bakalářské práce:	10. listopadu 2008
Akademický rok:	2008/2009

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V Ostravě dne 10. listopadu 2008

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ANNOTATION OF THESIS

GLOGER, M. *Construction of Effecter for Sampling Liquid.*
Ostrava: Department of Robotics, Faculty of Engineering VŠB – Technical University Ostrava, 2009, 50 s., Bachelor Thesis, head: Professor Pasi Kallio, Ph.D; Ing. Jan Burkovič, Ph.D.

Thesis is dealing sampling contamination liquid. Main idea is combine microtechnology techniques with ordinary sampling methods into one end effector. In the first part of thesis are schematically shown all possible structures of sampling system. Than different kind of convenient actuators for sampling task are presented and according comparison matrixes are selected three best of them. Topologies of two sampling methods are built up according selected actuators. These two solutions are deeply described and tested in laboratory. In the end of thesis the most convenient solution is chosen and comprehensive concept of service robot with this sampling method is modelled in system Pro/ENGINEER Wildfire 2.0.

ANOTACE BAKALÁŘSKÉ PRÁCE

GLOGER, M. *Konstrukce efektoru pro odběr vzorků kapalin*
Ostrava: katedra robototechniky, Fakulta strojní VŠB – Technická univerzita Ostrava, 2009, 50 s., Bakalářská práce, vedoucí: Professor Pasi Kallio, Ph.D; Ing. Jan Burkovič, Ph.D.

Bakalářská práce se zabývá odběrem kontaminovaných vzorků kapalin. Hlavní myšlenkou práce je kombinace mikrosystémových technologií s běžnými metodami odběru do jednoho koncového efektoru robotu. V první části práce jsou schematicky znázorněny všechny možné struktury systému odběru kapalných vzorků. Dále jsou prezentovány různé druhy vhodných akčních členů a na základě vyhodnoceni jsou vybrány tři nejlepší z nich. Topologie dvou rozdílných metod odběru je postavena na základě vybraných akčních členů. Tato dvě řešení jsou podrobně popsána a testována v laboratoři. Na závěr je vybráno nejvhodnější řešení a je vyhotoven 3D model, komplexního konceptu servisního robotu s touto metodou odběru, v programu Pro/ENGINEER Wildfire 2.0.

Contents of Thesis

List of used signs

l	[mm]	- length of shaft
d	[mm]	- diameter of shaft
F	[N]	- loading Force
m	[kg]	- mass of cartridge
M_o	[Nm]	- bending moment
A_y	[N]	- reaction in the support A in Y axis
B_y	[N]	- reaction in the support B in Y axis
A_x	[N]	- reaction in the support A in X axis
σ_{vmax}	[MPa]	- maximal equivalent tensile stress
τ_{Smax}	[MPa]	- maximal shear stress
δ	[mm]	- maximal deformation
σ_{OD}	[MPa]	- permissible bending stress
σ_O	[MPa]	- bending stress
R_m	[MPa]	- ultimate tensile strength
W_o	[mm^3]	- section modulus

1 Introduction

In nowadays when chemical, biological or nuclear menace are very actual, we have to think about manners how to make sampling in those contaminated areas and mainly how to make it safe for human beings. Only one solution occurs, thus, do it by service robot.

In this thesis is solved construction of end-effector, which will be able to do sampling operations of chemically, biologically or after nuclear accident contaminated liquid.

Structure will basically contain two parts microsampling and macrosampling. Former will contain Lab-on-a-chip technology, it means, sample of several micro litres will be introduced into small microplate in which will be done analyses already during fieldwork of robot. Microscopic volume of liquid will be taken from environment end than will be injected in microchannels of glass plate, this plate will contain sensor to detect dangerous substances in that liquid. This liquid will reach sensor in the plate and therefore analysis can be done immediately, depending up to technical support placed in a robot. The data from analysis will be sent in the centre of chemical or fire service unit situated in safety area near from contamination place. The latter will be activated only after unsuccessful or unclear results obtained from previously mentioned microsampling. This part will collect a big amount of liquid into a certain container and this will be transported in a laboratory.

There will be thought out two different solutions and after comparison the better one will be selected. Final solution will be modelled in software Pro/ENGINEER Wildfire 2.0.

2 Requirements List

a. *Volume*
   - Minimum required volume is 20µl in microsampling and for macrosampling is minimum volume which is necessary for subsequent laboratory analysis 100ml.

b. *Weight*
   - Maximum weight of whole end-effector should be 10 kg.

c. *Easy solution, where not such big accuracy and precision is required*
   - End-effector will contain also macro units and them plus with rough environment in which robot may operate cause vibrations in this effector.

d. *Temperature*
   - Big temperature deviations (increasing) can either affect results of analysis or even be dangerous for whole effector in case of some explosive liquid.

e. *Quick response ≤ 1 minute, fast liquid flow into a chip and containers, sufficient pressure.*
   - Special unit accredited to make sampling operation, will be waiting for data sent by robot, so as faster response as better solution.
   - Ability of sucking viscous liquid.

f. *Material*
   - Aggressive chemicals might be tested (glass, polyolifin Tygon® MHSL)

g. *Little sensitivity to bubbles and impurities*
   - Tasted liquid could be source of bubbles and impurities, necessity of actuator, which can deal with that without big problems.

h. *Cleaning*
   - If possible, liquid should not be in touch with an actuator
   - Easy changeability of tubing

i. *Disassemblability, dismountability*

j. *Filtering*

- if it is necessary, device should contain filters to avoid affecting of actuator by particles and impurities.

k. *Integrable device*

l. *Prise*

- Low prise is naturally important for whole efficiency of device, but under consideration must be also fact that robot will work in dangerous environments which can be destructive for all mechanism.

m. *Modularization*

- Sampling of unknown liquid needs different kinds of devices for analysis, different kinds of volume of sample and for purposes of exchangeability of tubing affected by dangerous liquid is modularization highly required task.

3 Basic Structure of System

3.1 Micropump and Microplate/Container

In the whole sampling process should be used basically three main components: microplate or container, microactuator and connection between them (e.g. tubing). Then other additional devices like sensors, valves or filtering etc. These components have to be mutually interconnected. At least three kinds of different structures can exist for this case.

A. *Valve controlled flow from source into microplate/container*

In figure 3.1. is illustrated interconnection of the each components. Fluid is first sucked into the tubing, first valve is open, after incoming sensor signal (fluid is near inlet of the pump), pumping is switched off and the valve one is closed, immediately a second valve is opened and pump starts to push liquid inside of microplate or container in case of macrosampling. Liquid will not affect pump, but very precise flow control is required.

B. *Source – pump – microplate/container*

In this case liquid must flow through the pump directly into the microplate/container (see figure 3.2.), it means, in overwhelming cases, be in touch with micropump chamber.

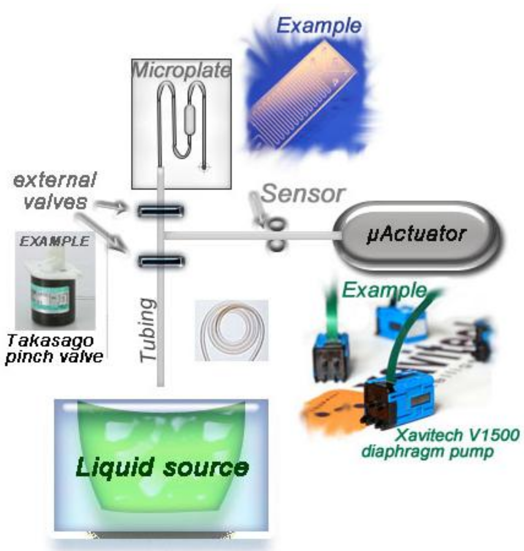


Figure 3.1. Valve controlled flow from source into microplate/container

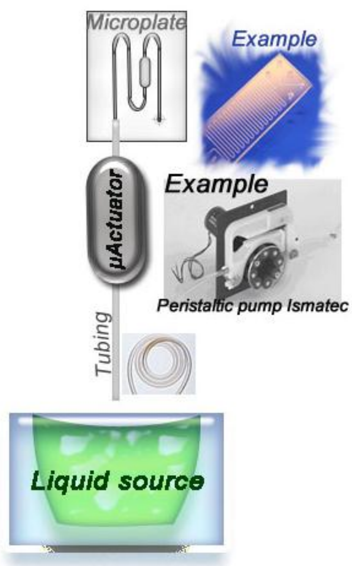


Figure 3.2. Source-pump-microplate/container

C. Source - microplate/container – pump

The third schema shows possibility to situate pump after microplate/container. Hence pumping pressure must go through microchannels and, thus, also through microsensor, it could make problems during analysis (see figure 3.3.).

Obviously all three structures have their own advantages and drawbacks. The main difficulty is selection of the pump which will move liquid into microplate and/or container. Hence, we have to make comparison matrices to achieve the most effective solution. Matrices should be done for each structure of microsampling system, because of principal similarity of solutions A and C is sufficient to make for these solutions one common matrix it means there will be two matrices with different results for every chosen pumps.

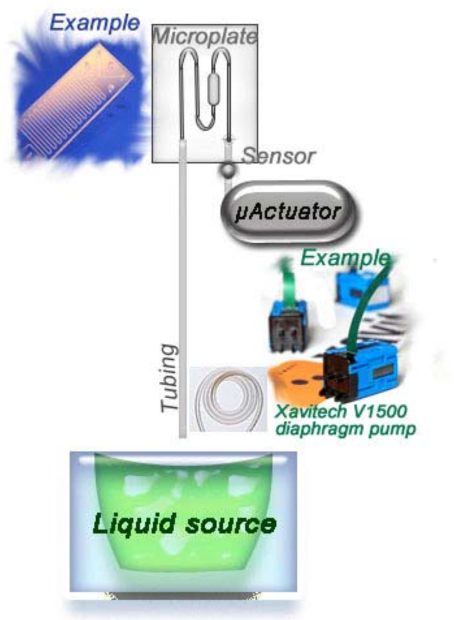


Figure 3.3. Source–microplate/container-pump

3.2 Pippette with Plate

Next totally different concept is composed from two separate parts moving mutually. First part is a pippette shown in figure 3.5 [1], with which will be done suction and injection process. Liquid from pippette will be introduced into a plate with microchannels shown in figure 3.4 [2].

Pippette will be fixed to some moving device inside the end-effector and after suction of required volume will be moved to the plate. Than the pippette approach a plate hole and accomplish the injection. Pipette should contain actuator which will accomplish the suction instead of human intervention.

This solution does not contain macrosampling, thus, this part is separated based on different idea.

Figure 3.4. Manifold chip

Figure 3.5. Pipette eppendorf

4 Actuators for Moving Liquid -Overview

a) Solenoid Pumps

These pumps are based on solenoid actuator which starts to make reciprocating movement when electricity is introduced. Basic principle is illustrated in figure 4.1, [3] and commercial example of solenoid pump from Lee Company is in figure 4.2, [3].

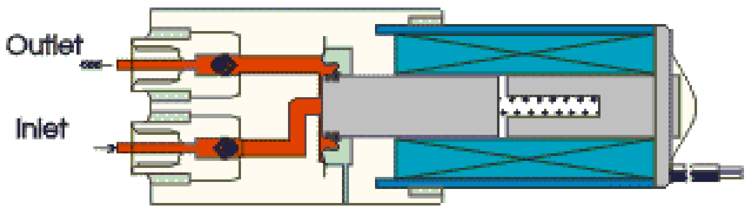


Figure 4.1. Cross-section of solenoid pump

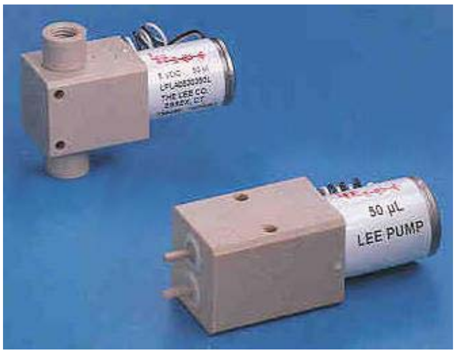


Figure 4.2. Solenoid pump from the Lee Company

b) Spiral-channel Viscous Pump

The pump works by rotating a disk with a spiral shaped channel below a flat plate covering the channel. The inlet and outlet of the pump are located at the spiral-channel ends, and the pump works due to the drag force generated by the moving action of the rotating channel with respect to the stationary disk [4].

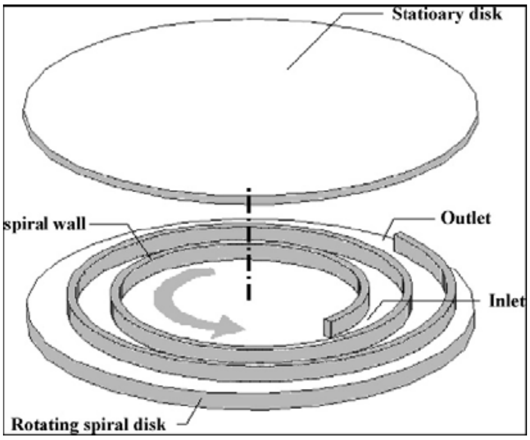


Figure 4.3. Principle of function of spiral-channel pump

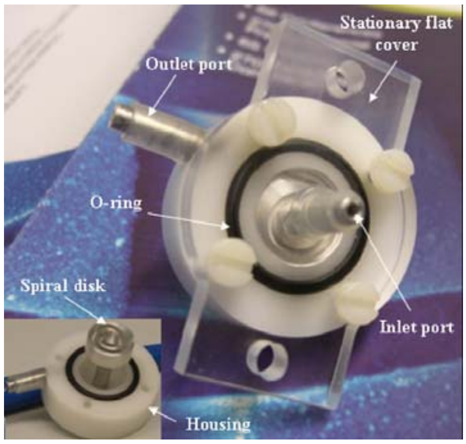
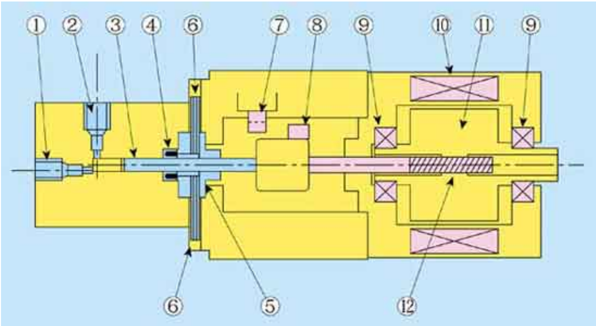


Figure 4.4. Whole device of Spiral-channel pump

c) Plunger Micro Pumps (stepping motor driven)

When the stepping motor coils ⑩ get excited in a clockwise direction, the internally threaded rotor ⑪ will start to rotate with the lead screw ⑫ moving leftward. The plunger ③ directly connected with the lead screw ⑫ will discharge the liquid inside the pump head through the outlet port ① or ②.One or two outlet ports may be selected. When the plunger ③ comes to the discharge completion position, the benchmark sensor ⑦ will detect the shutter ⑧, giving an electric signal. For intake of liquid, the motor coils ⑩ will need to get excited in a counter-clockwise direction. The rotor ⑪ will start to reverse. With the lead screw ⑫ and the plunger ③ moving rightward, the liquid will enter the inlet port ① or ②. The discharge and suction volumes can be controlled by means of the pulse number of motor. In figure 4.6 is illustrated the commercial example stepping Motor Driven Plunger-Type Micro Pump UNIFLOWS CO.,LTD. [5]



① INLET or OUTLET PORT 1
② INLET or OUTLET PORT 2
③ PLUNGER
④ PLUNGER SEAL
⑤ PLUNGER GUIDE
⑥ WASHING PORT for PLUNGER SEAL
⑦ BENCHMARK SENSOR
⑧ SHUTTER
⑨ BEARING
⑩ MOTOR COILS
⑪ MOTOR ROTOR
⑫ LEAD SCREW

Figure 4.5. Internal Mechanism of plunger micropump

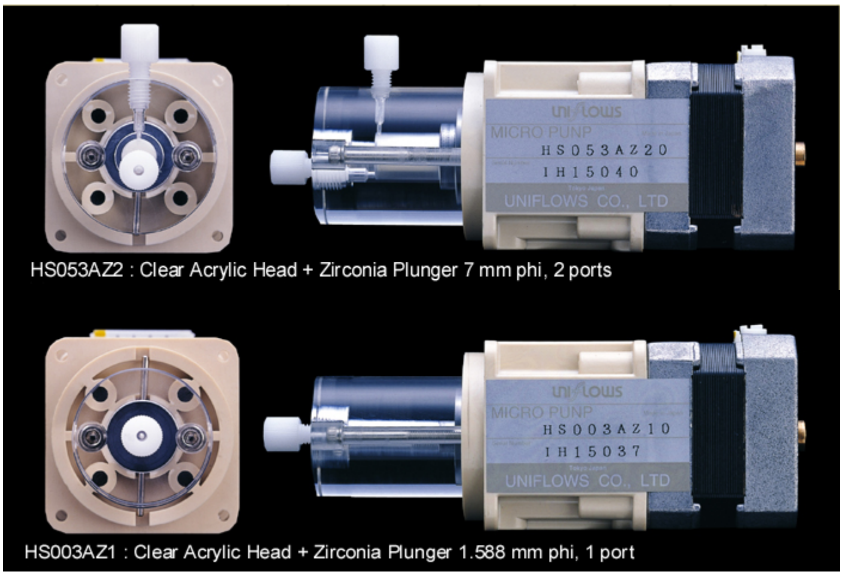


Figure 4.6 stepping Motor Driven Plunger-Type Micro Pump UNIFLOWS CO.,LTD, one and two out/inlet ports.

d) Micro Annular Gear Pumps

Micro Annular Gear Pumps are rotary pumps that are constructed with an externally toothed internal rotor as well as with an annular tooth external rotor, which bear slightly eccentric to each other. During rotation of the rotors around their offset axis, the pumping chambers simultaneously increase on the induction side and decrease on the delivery side of the pump. A homogeneous flow rate is generated between the kidney-shaped inlet and outlet [6]. Basic principle is illustrated in figure 4.7, [6] and commercial example of micro annular gear pump from Micropumps Inc. is in figure 4.8, [6].

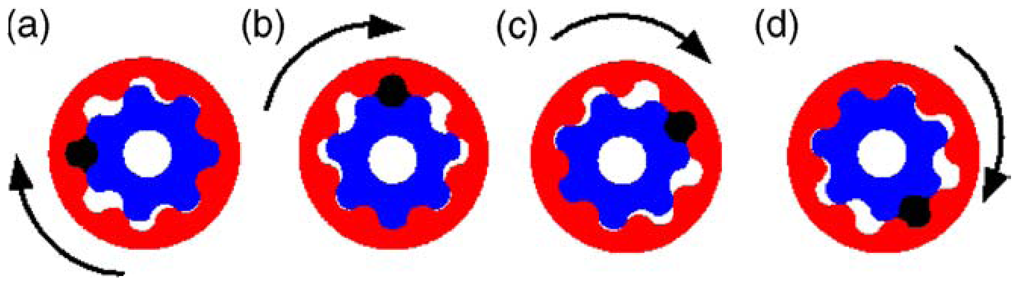


Figure 4.7 Rotor in engagement, [6]

Figure 4.8. Micro annular gear pump Model 2900/2905

e) Centrifugal Pumps

Centrifugal pumps consist of an impeller rotating within a casing. Liquid directed into the centre of the rotating impeller is picked up by the impeller vanes and accelerated to a high velocity. When the liquid in the impeller is forced away from the centre of the impeller, a reduced pressure is produced and consequently more liquid flows forward. Commercial example is in figure 4.10, [6].

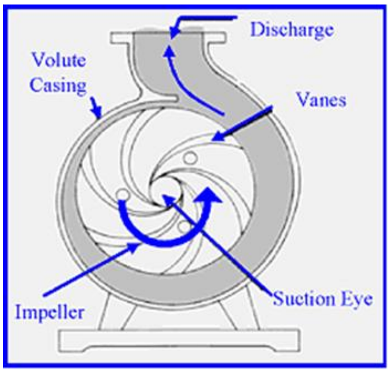


Figure 4.9. Principle of function centrifugal pump

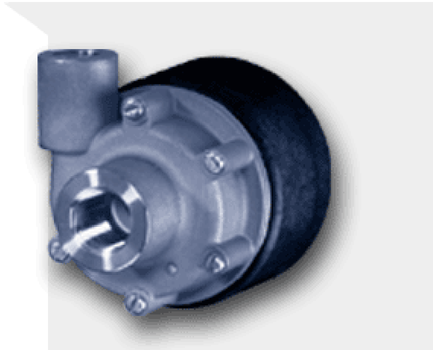


Figure 4.10. Centrifugal Pump series CA Micropumps Inc.

f) Gear Pumps

Principle of function gear pumps is illustrated in figure 4.11, [8]. Liquid is pulled into the pump room due to rotational movement of two gear wheels. The pump with the oval wheels provides a larger pump room. Inside this kind of pump could be introduced fluids even with solid particles by the roll off of gear wheels. Commercial example is in figure 4.12, [6].

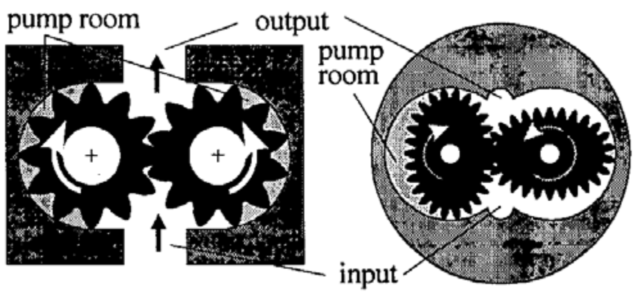


Figure 4.11. Function of gear pumps

Figure 4.12. Gear pump Series GA/GAH Micropumps Inc.

g) Single-disk and Double-disk Viscous Micropumps

The two axially collinear disks, or the disk and the top pump housing, are separated by a small gap. The wiper is situated between the spinning disk(s). Figure 4.13 shows a cross-sectional view of the disk pumps. The spinning of the disk(s) cause a net movement of fluid due to the viscosity of the fluid, and the transfer of moment from the disks to the fluid. The wiper acts to "wipe" the fluid off the disk(s), and to direct the fluid into the outlet channel. Figure 4.14 shows the movement of the fluid through the single-disk pump as indicated by the small arrows, [9].

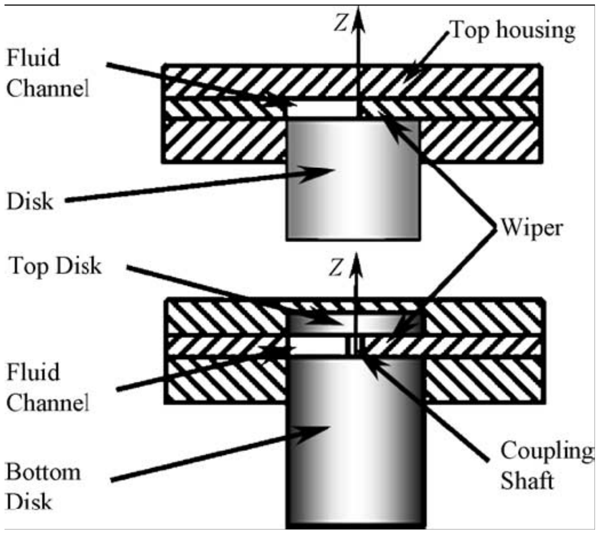


Figure 4.13 Cross-sectional view of the single and double-disk pumps.

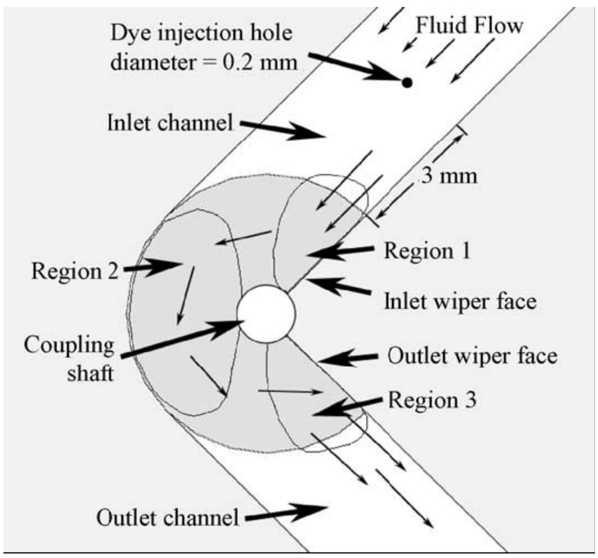


Figure 4.14 Path of fluid flow

h) Oscillating Displacement Pump, Diaphragm Pumps

- Mechanically driven

The motor causes an internal axle to move back and forth. This action is transferred to the elastic diaphragm which, in cooperation with the non-return valve, produces the pumping effect. Principle of function is shown in figure 4.15, [10]. Commercial example can be seen on figure 4.16, [11].

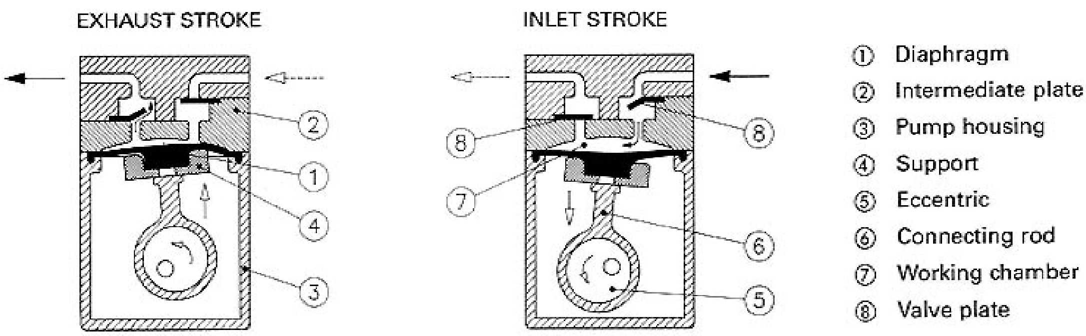


Figure 4.15. Function of diaphragm pump

Figure 4.16.intelligent diaphragm pump Xavitech V200-3.2-26V LIQ

- Piezoelectrically driven

This kind of pump has same principle as previously mentioned oscillating displacement pump, but instead of motor and eccentric wheel, here is membrane which contain piezoelectric disk, which bends when positive voltage is applied, as we can see very simplified on Figure 4.17, in following figure is shown commercial application from Bartels Mikrotechnik type mp5, [12]

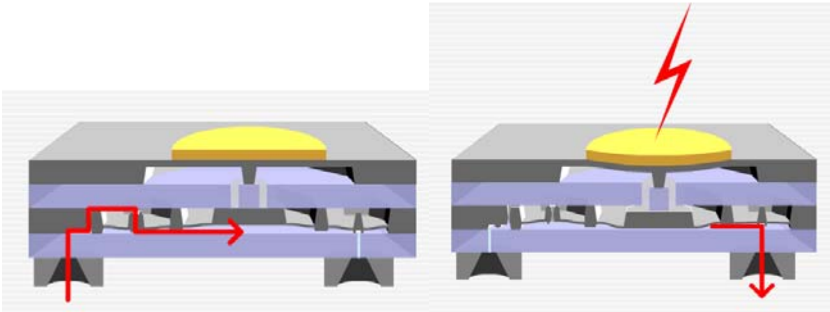


Figure 4.17. Function of piezoelectrically driven diaphragm pump

Figure 4.18. Micropumps from Bartels Mikrotechnik: mp5

i) Peristaltic Pumps

Tubing is used as the pump chamber and may be single or multichanneled. The fluid confined in the tubing is displaced when two or more rollers squeeze the tubing against the walls of the pump housing. Changing the tubing size or the rotor speed will vary the flow rate. Maximum pressure capability is limited to the tubing. Commercial example of peristaltic pump from ISMATEC is on figure 4.19, [13].

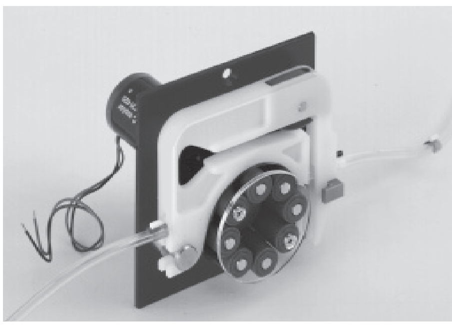


Figure 4.19. Peristaltic pump ISMATEC

5 Comparison Matrices

	Solutions for sampling of contaminated liquid										
		Source – pump – microplate/container									
		MICROPUMPS									
REQUIREMENTS	Pippette with plate	Solenoid Pumps	Plunger Micro Pumps	Spiral-channel viscous pump 2 ports	Micro Annular Gear Pumps	Centrifugal pumps	Gear pumps	Single-disk and double-disk viscous micropumps	Oscillating displacement pump, diaphragm pumps	Peristaltic pumps	piezoelectrically driven diaphragm pump
Volume	●	◑	◑	◑	●	●	●	◑	●	●	○
Robust construction(avoid to accuracy movements)	○	●	●	●	●	●	●	●	●	●	●
Avoid temperature changes	●	●	●	●	●	●	●	●	●	●	◑
Flow rate(fast response)	○	●	●	○	●	●	●	○	●	●	◑
sufficient pressure	●	●	●	○	●	●	●	○	●	●	◑
Inert matter(aggresive chemicals resistant)	○	○	○	○	○	○	○	○	○	●	
Little sensitivity to bubbles and impurities	●	◑	◑	◑	◑	◑	◑	◑	○	●	
Liquid should't be in touch with actuator										●	
Disassemblability, dismountability	●	◑	●	◑	◑	◑	◑	◑	●	●	●
Filtering										○	
Ability of sucking viscous liquid	●	◑	●	◑	●	◑	●	●	●	◑	
Integrable device (dimensions)	○	◑	●	●	◑	◑	●	●	●	●	●
Prise	◑	◑	◑	●	◑	◑	◑	●	○	●	●

(orange)	- strong requirements
●	- strong driver (9)
◑	- medium driver (3)
○	- some driver (1)

	Solutions for sampling of contaminated liquid									
		Source - microplate/container – pump								
		MICROPUMPS								
REQUIREMENTS	Pippette with plate	Solenoid Pumps	Plunger Micro Pumps	Spiral-channel viscous pump 1 port	Micro Annular Gear Pumps	Centrifugal pumps	Gear pumps	Single-disk and double-disk viscous micropumps	Oscillating displacement pump, diaphragm pumps	Peristaltic pumps
Volume	●	◒	◒	X	●	X	X	X	●	X
Robust construction(avoid to accuracy movements)	○	●	●	X	●	X	X	X	●	X
Avoid temperature changes	●	●	●	X	●	X	X	X	●	X
Flow rate(fast response)	○	●	●	X	●	X	X	X	●	X
sufficient pressure	●	●	●	X	●	X	X	X	●	X
Inert matter(aggresive chemicals resistant)	○	●	●	X	●	X	X	X	●	X
Little sensitivity to bubbles and impurities	●	◒	◒	X	◒	X	X	X	○	X
Liquid should't be in touch with actuator		●	●	X	●	X	X	X	●	X
Disassemblability, dismountability	●	◒	●	X	◒	X	X	X	●	X
Filtering				X		X	X	X		X
Ability of sucking viscous liquid	●	◒	●	X	●	X	X	X	●	X
Integrable device (dimensions)	○	●	●	X	◒	X	X	X	●	X
Prise	◒	◒	◒	X	◒	X	X	X	●	X

- strong requirements
● - strong driver (9)
◒ - medium driver (3)
○ - some driver (1)

5.1 Results

There were chosen three different microactuators after precise probing of comparison matrices.

From the first matrix is obvious that the biggest amount of strong drivers has peristaltic pump, after further consideration was found out, that this actuator is really the best in connection Source – pump – microplate/container and therefore was selected and will take part on one of the final solutions.

Second matrix has not such evident result, so solution is rested on two pumps. Diaphragm pump is powerful, cheap and easily integrable these characters was by the way main advantages why was this pump chosen as second actuator for sampling process.

The plunger micropump could not be omitted from consideration, because its stepper motor can achieve very big accuracy so it is best for microsampling, hence these pump represents third choice.

Recapitulation:

- ✓ Peristaltic pump
- ✓ Diaphragm pump
- ✓ Plunger pump

6 Testing 1

There were tested two different kinds of pumps in the Testing 1, namely peristaltic pump and diaphragm pump. Both pumps were considered to use in micro and in macro sampling as well. There was also examined how pumps work in case of pumping either low or high viscous liquids. Results of testing are times in which pumps are able to fill microplate with volume 140μl (shown in figure 6.1) and also container with volume 100ml (figure 6.2), we are interested in rotational speed of peristaltic pump head, under pressure of diaphragm pump and diameters of used tubing as well. Testing was done in room temperature 20°C.

Liquids were divided in three viscosity classes:

Low viscosity -	water	1.003×10^{-3} Pa·s
Medium viscosity -	washing up liquid	1 Pa·s
High viscosity -	yogurt	8 Pa·s

Figure 6.1. Microplate 140μl

Figure 6.2. Container 100 ml

6.1 Peristaltic Pump

Gilson minipuls 3 peristaltic pump was used for testing purposes. Properties of this pump are written below, [14].

Flow Rate	Standard flow rates (1, 2, 4, or 8 channels): 0.3 μL/min–30 mL/min at a maximum pressure of 0.5 MPa. High flow rates (2 or 4 channels): 1 mL/min–220 mL/min at a maximum pressure of 0.3 MPa
Head Speed	Continuous adjustment from 0 to 48 rpm by 0.01 rpm increments up to 9.99 rpm and by 0.1 rpm increments above 10 rpm
Tubing Diameter	Standard model: 0.25–4 mm (ID) High-Flow model: 2–8 mm (ID)
Pump Heads	Standard model: 1-, 2-, 4-, or 8-channel heads with 10 stainless steel rollers per head High-Flow model: 2- or 4-channel heads with five stainless steel rollers per head

Figure 6.3. Gilson minipuls 3 peristaltic pump

- Microsampling

In microsampling part was considered to use only one tubing with inner diameter 0,056inch = 1,42mm, because as will be clarified later this diameter is sufficient and bigger one is not necessary. The tube length is 45 mm and was tested during different rotational speeds of peristaltic pump head.

Following results cover time necessary to fill whole length of tubing and microsampling channels of volume 140μl.

Water

Speed [rpm]	Diameter [mm]	Time [s]
20	1,1422	16,37
30	1,1422	10,20
35	1,1422	9,05
40	1,1422	7,40
48 (max)	1,1422	6,57

In order to obtain reliable result during liquid flow through reaction chamber with microsensor was decided to choose speed 35 rpm for other testing.

Washing up liquid

Speed [rpm]	Diameter [mm]	Time [s]
35	1,1422	12

Yogurt

Speed [rpm]	Diameter [mm]	Time [s]
35	1,1422	11

As is obvious from results there are no big differences in pumping of liquids with different viscosities, and we can very easily regulate flow velocity by setting of rotational speed, thus, all in all this solution is very convenient for microsampling.

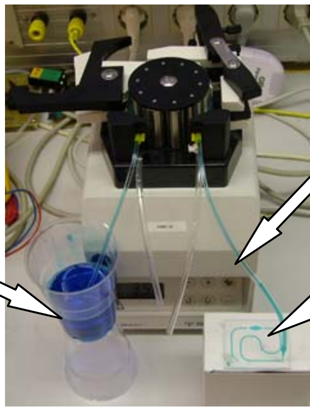


Figure 6.4. Example of testing with peristaltic pump

- Macrosampling

Three different inner diameters of tubing were used in macrosampling to achieve bigger velocities and better times. Speed of rotational head was set on maximum value 48 rpm.

Water

Speed [rpm]	Diameter [mm]	Time
48 (max)	1,1422	< 10 min
48 (max)	3,175	4 min 05 s
48 (max)	5	1 min 30 s

Washing up liquid

Speed [rpm]	Diameter [mm]	Time
48 (max)	1,1422	< 10 min
48 (max)	3,175	5 min 10 s
48 (max)	5	1 min 50 s

Yogurt

Speed [rpm]	Diameter [mm]	Time [s]
48 (max)	1,1422	< 10 min
48 (max)	3,175	6 min 30 s
48 (max)	5	2 min 15 s

From tables is evident that with increasing of diameter, time of pumping is decreasing, so if it is possible insert appropriate diameter and set sufficient speed of rotational head we can easily achieve low times of pumping 100 ml. Another possibility how to obtain better times is join more than one pumping tubes into one container (e.g. if it is joined two tubes in one container time of pumping will be double smaller). Thus this solution is with appropriate choice of pump very flexible and convenient for macrosampling as well.

6.2 Diaphragm Pump

As second option was chosen diaphragm pump Schwarzer Präzision SP200EC-LC (Figure 6.5). In testing of diaphragm pump was used those devices (see Figure 6.6):

- Diaphragm pump SP200EC-LC (number 1 in Figure 6.6), [15]:

Motor	power source 6 Vdc	
	motor type iron core current draw 130 mA	
Pneumatic Performance	free flow [ml/min]	680
	100 mbar [ml/min]	400
	100 mbar [ml/min]	350
	max. pressure [mbar]	680
	max. vacuum [mbar]	490

Figure 6.5. SP200EC-LC

- Pressure sensor for control of under pressure (number 2 in Figure 6.6).
- Fluke 112 Digital Multimeter (number 3 in Figure 6.6).
- Iso-tech IPS601A analogue bench power supply (number 4 in Figure 6.6).

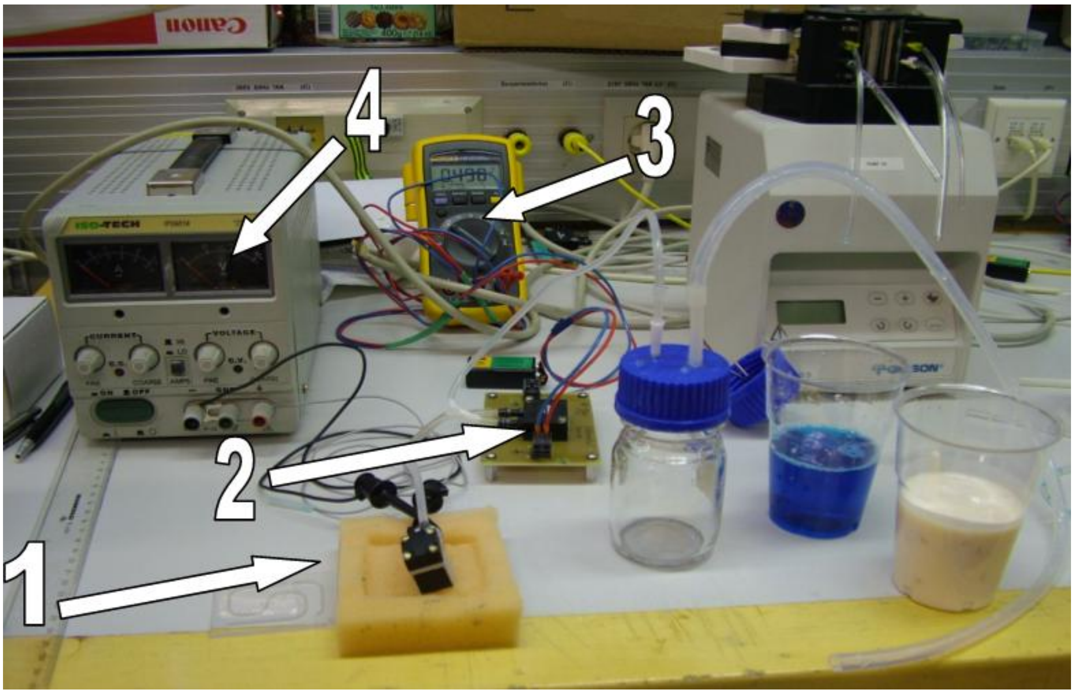


Figure 6.6. Testing of diaphragm pump

- Microsampling

There was used tube with the smallest inner diameter 1,422 mm and maximum voltage load 6V in microsampling but in this case was pumping of liquid into microplate too fast, only few millisecond. It is not good for analysis made by microsensors. Smaller voltage load was tested as well, but in this case was danger of overheat of motor if tube is clog or squeeze accidentally, because air flow is not enough powerful.

So all in all in this testing was found out that solution diaphragm pump in connection Source-microplate/container-pump (see figure 3.3) is <u>inappropriate in microsampling part</u> and thus is excluded from consideration.

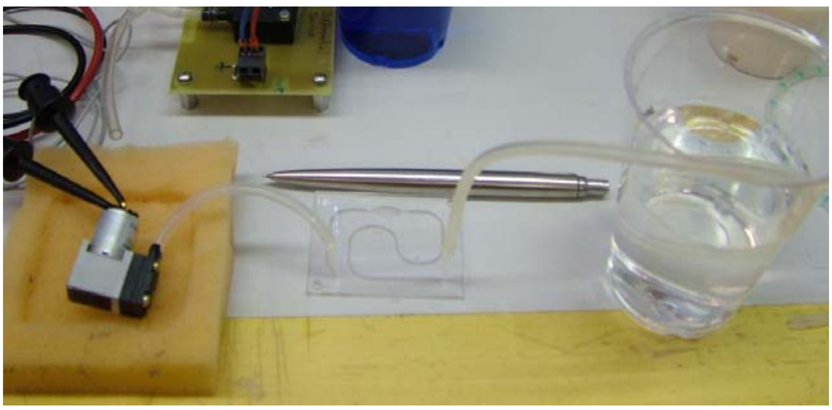


Figure 6.7. Microsampling with diaphragm pump

- Macrosampling

Tube with diameter 5 mm and voltage load of 6V was used. Time in which pump was able to fill 100 ml was measured. Results are shown in table below.

liquid	Diameter [mm]	Voltage [V]	Time [s]
water	5	6	31
Washing liquid	5	6	55
yogurt	5	6	59

There were obtained very good results in macrosampling part, times are convenient for sampling purposes and is also possible to pump high viscous liquid without any problems.

6.3 Summary of Testing 1

Testing 1 have probed into use of peristaltic and diaphragm pump, it was proved that peristaltic pump can be used in microsampling and also in macrosampling, but there has to be found some more powerful pump then Gilson minipuls 3 to achieve faster flow, or could be introduced two or more tubes into one container.

In case of diaphragm pumps SP200EC-LC was demonstrated that it is inconvenient use them for microsampling purposes, because of too fast flow, which could make troubles during analysis. On the other hand it was presented that membrane pump is highly appropriate for macrosampling.

7 Solution 1

(Connection Source – Pump – Microplate/Container with Peristaltic Pump)

7.1 Description

Idea is combination of micro and macro sampling which will be done by one pump. Thus, the peristaltic pump is the main part of this solution. Whole device will be composed of tubes, switching mechanism (described in point 7.3 of this chapter), microsensors, peristaltic pump, microplates and two containers of volume 100 ml. Motor controller of peristaltic pump and the other electronic devices will be placed on a wheelframe of the robot. Pump will be fixed inside of the end-effector and rest of devices will be inserted in special cartridge. This cartridge was invented in order to easy-changing of tubes. The cartridge will be removed from the end-effector after every fieldwork of the robot and the tubes inside will be replaced by new set. In order to achieve multiply sampling two plates and containers are involved in one cartridge.

With "clever" service robot system on board is even feasible to add special buffer with several cartridges inside and thus obtain as comprehensive and extraordinary solution as possible. In chapter 11 is briefly described structure and shown model of such buffer and simply constructed service robot, to demonstrate how efficiently this device could be used.

7.2 Peristaltic Pump

Heard of this solution is peristaltic pump. It is necessary find pump which is accurate and powerful at the same time, because microsampling needs as fluent and continuous flow as possible and macrosampling on the other hand needs fast flow to avoid big delays during work of robot.

It was established macrosampling time should not be more than one minute, hence searched pump's maximum flow rate has to be more than 100 ml per one minute. As was mentioned, necessity of fluent flow is required, this is possible achieve by increasing of number of pump rollers. Generally, there are pumps with from two to twelve rollers in use. The best numbers of rollers in combination with power, flow rate and fluency is 8-12 pump rollers. Whole device contains two microplates and two containers, it means, that necessity of four output tubes occurs.

Range of pumps, which can be used rapidly decrease after consideration of criteria mentioned above.

Tubing pump MCP-E from Micropump Inc. was chosen (see picture 7.1). Flow rate of this pump is up to 230 ml per minute with tubing of inner diameter 3,17mm (0.125 inches). This pump has four channels and eight rollers as well (all the others necessary data is possible to find in appendix 1, [16]).

Figure 7.1. Tubing pump MCP-E from Micropump Inc.

7.3 Switching Mechanism Solutions

Switching mechanism means solution of switching between micro and macro sampling and also between particular containers and microplates.

There were *two solutions* under consideration:

Firstly was considered system, which will automatically open and close the clippers of pump head, it means that clipper would squeeze the tube which should be used. Mentioned system involve shape memory alloy springs, which would be heated and cooled by electric current in order to divide stream into either microplate or container. However, this solution become quite complicated and several other mechanisms are required here. In order to achieve more reliable and simple solution was necessary to think out another mechanism.

Second idea is very simply use external valves to control streams between required branches while all tubes are squeezed permanently in pumping head. External ones, because of dangerous and unpredictable liquid, which can make some damages or can destroy internal valves and also because of easy-changing of tubing set. Thus, second solution of switching mechanism was chosen and hence external valves are required.

7.4 Other Devices (valves, tubing, sensors)

Valves

Switching mechanism solution requires external valves as mentioned above. With regard to multi channel type of pump (four tubes), it is necessary to involve at least two valves, idea is first of all split flow between two separated sampling set consist of same microplate and container (in order to achieve multiply sampling). For this purposes is sufficient two way valve, which is still in one way normally closed and in second normally opened, the best is external pinch valve from Bio-chem Valve Inc. series number 100P as is shown in Figure 7.2 (valve in right side).This valve is capable of squeezing tubes of outer diameters up to 11,1mm (7/16″). Than each of these two tubes will be split into two branches again, in this case will occur four outputs, for control flow in these four branches is possible to use the same valve as mentioned above but in dual design (in both sides two inputs) see figure 7.2 (valve in left side). For further information about these Bio-chem components see reference [17].

Figure 7.2. External pinch valve from Bio-chem Valve Inc.

Tubing

Many kinds of tubes are available for different kinds of applications, for purposes of sampling chemically, biologically contaminated liquids or even liquids with certain amount of radiation after some nuclear accident or just from environments where radiation is still in dangerous level, is possible to determine and specify just few particular tube materials. There are chosen and described three the most convenient materials for application.

TYGON® R-3603 Laboratory Tubing [18]

- Outstanding chemical resistance
- Increases productivity in peristaltic pumps
- Non-oxidizing and non-contaminating
- The glassy-smooth inner bore
- Long-lasting and crack-resistant

TYGON® 2075 Ultra Chemical Resistant Tubing [18]

- Resistant to highly aggressive chemicals
- Virtually unaffected by acids, bases, ketones, salts and alcohols
- Plasticizer-free - minimizes risk of fluid contamination
- Exceptionally smooth inner surface inhibits particulate build up

CHEMFLUOR® PVDF Tubing [18]

- High purity/low extractables
- Excellent chemical resistance
- UV and radiation resistance
- Mechanical strength and toughness

As it is obvious, for radioactive liquid is appropriate use Chemfluor® tubing and for some aggressive chemicals is good Tygon. Decision which kind of tube will be used depends on type of liquid, but for our solution with peristaltic pump is the best to use TYGON® R-3603 Laboratory Tubing the inner diameter of tubing is 3,17 mm (0,125 inches), outer diameter is 6,35 mm (0,25 inch) and wall thickness is 1,59 mm.

Sensors

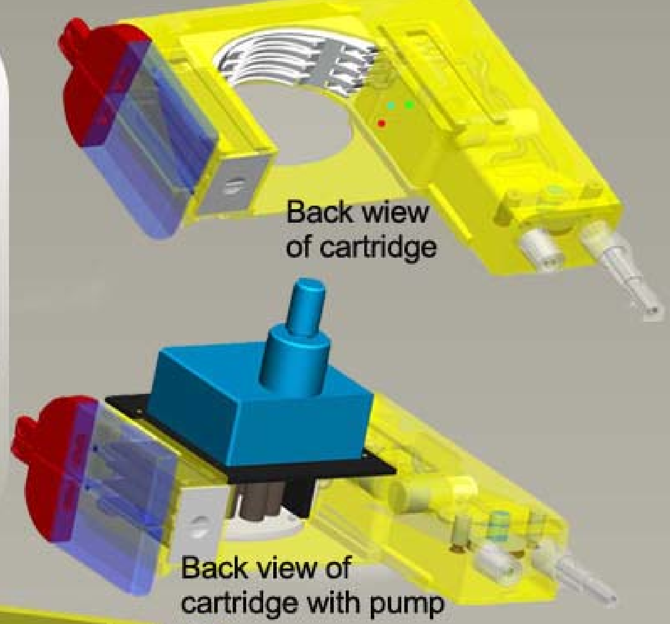
In solution one can be implemented many sensors for different measurements, for instance in case of viscosity determination is possible just placed two phototransistor sensors in certain distance between them by using two Slotted Optical Switchs [19].

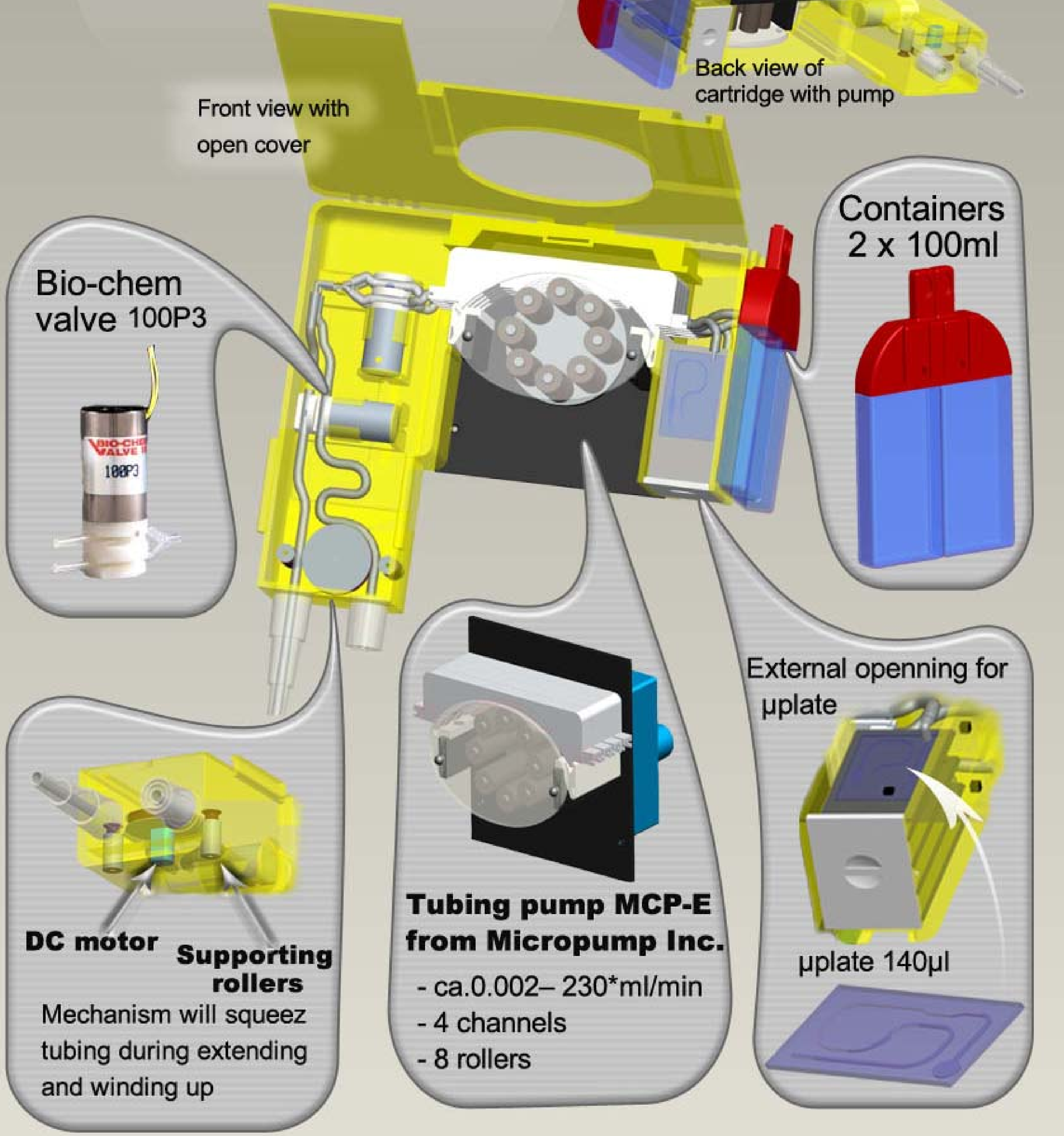
For simplify this solution, there are only four sensors in use. First for liquid level detection in containers, this sensor is mounted in the wall of cartridge shell near the container input. When first sensor starts indicate present of liquid, macrosampling will be automatically switched off. Second sensor is for switching off microsampling, thus, for determining fullness of microplate, this sensor is directly fixed to microplate. Sensors are simple opto-switches (consists of an infrared emitting diode and a phototransistor), small 4x4x4 mm opto-switch, reflective sensor HOA1397-001 from Honeywell company is sufficient for our purposes [20].Rotary potentiometer is used to control DC motor for switching sampling branches via wind up and push forward tubes. This potentiometer is placed in one of the supporting rollers. Inside microplates are located chemical or bio sensors for analysis.

7.5 Design of Whole Device

Description of sampling :

- Extended tubing will reach source
- Pump will start fill microplate (analysis)
- if no relevant results obtained
- Pump will fill container
- When first container is full than switching on second branch by rotation of DC motor, winding up and extending of tubing in the suction part
- Again same procedure in second branch





Specifications – overview of SCOOP 1

Cartridge	
Dimensions (height x width x depth)	250mm x 282mm x 74mm
Dimensions with pump	250mm x 282mm x 204mm
Material	KYNAR® PVDF
Weight (kg)	1,1752
Tubing	
Diameter (inner x outer x wall thickness)	3,17mm x 6,35mm x 1,59mm
Used length (m)	Approximately 1,8
Type	TYGON® R-3603 Laboratory Tubing
Fittings	1x Y-05P(split in 2 ways), 2x 90°angle fitting
Weight (kg)	0,028
Peristaltic Pump	
Type	MCP-E
Time of pumping microsampling (150μl)	Several seconds
Time of pumping macrosampling (100ml)	Maximal load less than 30 seconds
Weight (kg)	1,7
Valves	
Pieces	2
Type	Bio-chem External pinch valves 100P 2way/dual
Weight (kg)	2 x 0,142
Sensors	
Pieces	3
Type	2x opto-switch HOA1397-1, rotary potentiometer
Weight (kg)	0,04
Microplates	
Pieces	Possible to place 4 microplates (normally 2 in use)
Dimensions (height x width x depth)	55mm x 35mm x 2mm
Max. applicable dimensions	88mm x 42mm x 10mm
Material	Borosilicate glass
Weight (kg)	0,0094
Sensor for detection of fullness	1x opto-switch HOA1397-1
Reaction sensor for analysis	chemical or bio-sensors
Containers	
Volume	2 x 100ml
Dimensions (height x width x depth)	145mm x 55mm x 20mm
Material	Borosilicate glass
Weight (kg)	0,25
Weight of whole device (kg)	**3,98**

8 Testing 2

Second testing was aimed to determine function of plunger pump for sampling purposes. Pump was tested directly in “A” connection (Valve controlled flow from source into microplate/container, see Figure 3.2), it means liquid was not in touch with pump. Hence, testing 2 was done for solution 2. There was used tubing with inner diameter 1 mm and outer diameter 3 mm. Microplate was same as in testing 1. There was also examined how pump works in case of pumping either low or high viscous liquids as in testing 1. Result of testing is the most convenient frequency of stepper motor for filling microplate in time, which is the best for analysis. There was found out that plunger micropump in inappropriate for macrosampling, because of low flow range and also structure of whole device represents quite slow procedure. The user interface was done in LabView software, for determining frequency, motor direction and switching valves. Testing was done in room temperature 20°C.

8.1 Plunger Pump

There was chosen Variable volume pump configuration "B" 750µl from the Lee Company (2D drawing is available in appendix 2), [3].

Specifications:

- Lightweight - Approx. 300g
- Low Power – 2,3 W/ph
- Up to 750 µl/sec dispense rate
- Bipolar stepper motor
- Drive current for 750 µl pumps: 275 mA RMS per phase
- Full Step Volume Increment 1,5 µl, Pump Volume Range 750 µl
- Maximum discharge pressure: 15 psig

Figure 8.1. Variable volume pump configuration "B" 750µl from the Lee Company

8.2 Schema of Testing

Firstly LabView based software is set up on certain frequency (stepper motor frequency), valve one is switched OFF (open) and valve two is ON (closed). After this set up plunger pump is activated and liquid is sucking from source to opto-switch sensor B through tubing. If liquid reach sensor B than frequency will be changed to lower one in order to achieve good results from analysis. Direction of flow is changed, valve one is closed and valve two opened as well. Hence, microplate is starting to be filled. When liquid will flow to sensor A and distance 178 mm between sensors A and B will become empty pump is going to be deactivated and whole procedure is done.

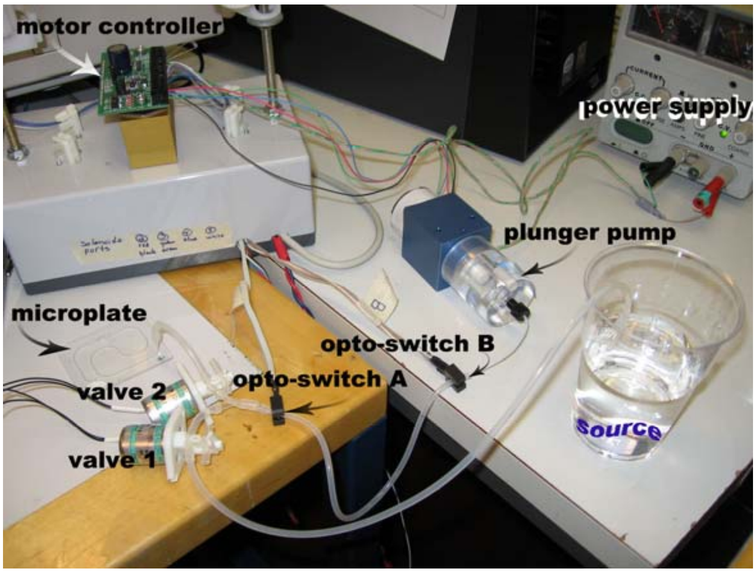


Figure 8.2. Laboratory testing of plunger pump

8.3 Results

There were set up different kind of frequencies to find out the most convenient speed of flow for analysis and sensor detection. The best combination of frequencies for microsampling is written in the table below.

Fill	**l (mm)**	**f (Hz)**	**t (s)**	**Description**
Tubing	428	100	10	Liquid goes through tubing of length 428 mm from source to sensor B situated near the pump inlet, valve two is closed
Tubing + microplate	72	10	40	When liquid reach the sensor B then valve one close , valve two open, pump change direction of plunger movement and frequency to 10 Hz. Liquid starts go into the microplate through tubing of length 72 mm
Total	**500**	**-**	**50**	

9 Solution 2

9.1 Description

According of results from testing two is obvious this system has to be divided into two independent areas, microsampling part and macrosampling part. Thus, more complicated system than in solution one appears in this case.

Microsampling structure is resting on concept from Testing 2 (valve controlled flow from source into microplate), so all necessary description of function is possible to find in Testing 2 part. However, one difference between this solution and testing is appeared, instead of two valves there is going to be used only one dual valve, which will handle liquid flow in tubes. All components which are regularly replacing after every fieldwork will be again situated in removable cartridge like in solution one and pump will be fixed firmly into the end effector.

Macrosampling will be independent part as mentioned before. Connection will be done according C. variation (Source – microplate/container – pump) described in third chapter "basic structure of system". Pump which will be used in macrosampling has been tasted in the Testing 1. It is namely diaphragm pump Schwarzer Präzision SP200EC-LC. This pump performs sufficient power and for these purposes big accuracy is not required, hence, this pump is adequate. Tubing will be situated in the similar removable cartridge like for microsampling. The pump will be again firmly inserted into the robot end tool and container is going to be easily removed after robot work.

9.2 Components

Microsampling

- Plunger pump (see testing 2)
- Valves (see figure 9.1.)
- Sensors (see figure 9.2.)

Two Slotted Optical Switch sensors will be in use, first near the pump inlet to avoid touch liquid with the pump and the second one will be in appropriate distance in way of same tube like first sensor to measure volume of liquid injected into the microplate.

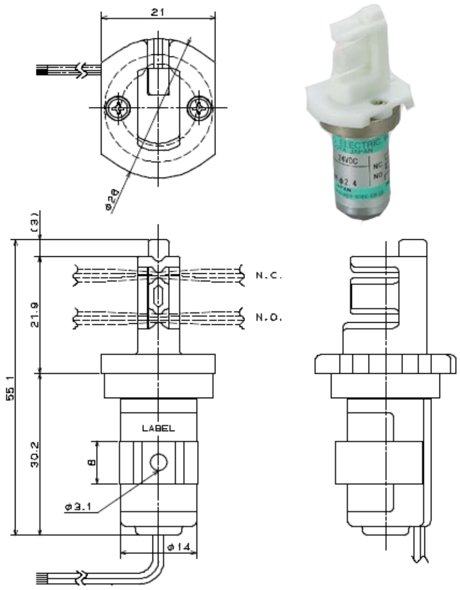


Figure 9.2. Takasago Electronics INC Pinch Valve PE-0810W Dual [22]

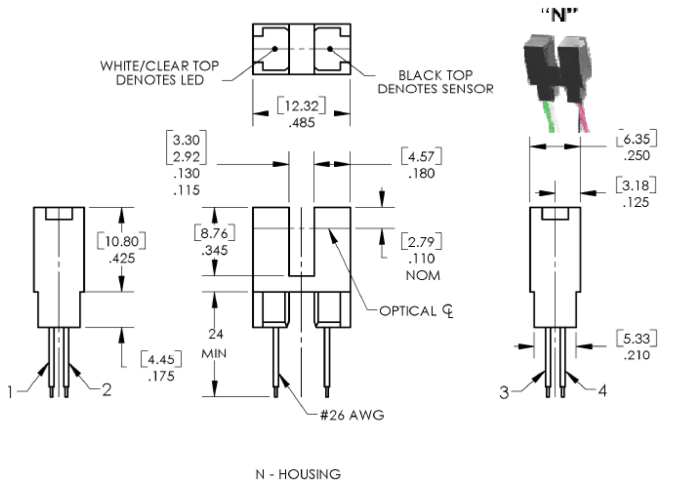


Figure 9.3. TT Electronic Slotted Optical Switch OPB380N11 [23]

- Stepper motor controller

There was chosen intelligent motion system IM481H plus High Performance Ultra-Miniature Hybrid Microstepping Driver for control stepper motor of plunger pump.

The IM481H PLUS is a high performance, yet low cost microstepping driver that utilizes advanced hybrid technology to greatly reduce size without sacrificing features. The IM481H PLUS is exceptionally small, easy to interface and use, yet powerful enough to handle the most demanding applications.

The IM481H PLUS has 16 built-in microstep resolutions (both binary and decimal). The resolution can be changed at any time without the need to reset the driver. This feature allows the user to rapidly move long distances, yet precisely position the motor at the end of travel without the expense of high performance controllers, [24].

FEATURES:

- Very Low Cost
- Ultra Miniature (1.1 x 2.7 x 0.175 inches),(28 x 69 x 4.4 mm)
- Advanced Hybrid Design
- High Input Voltage (+12 to +48 VDC)
- High Output Current (1.5 Amps RMS, 2.1 Amps Peak)
- Replaces Mechanical Gearing for Smoothness and Positioning
- Up to 51,200 Step/Rev with 1.8° Motor
- 16 Selectable Microstepping Resolutions can be Changed On-the-Fly
- Automatically Switches Between Slow and Fast Decay for Unmatched Performance

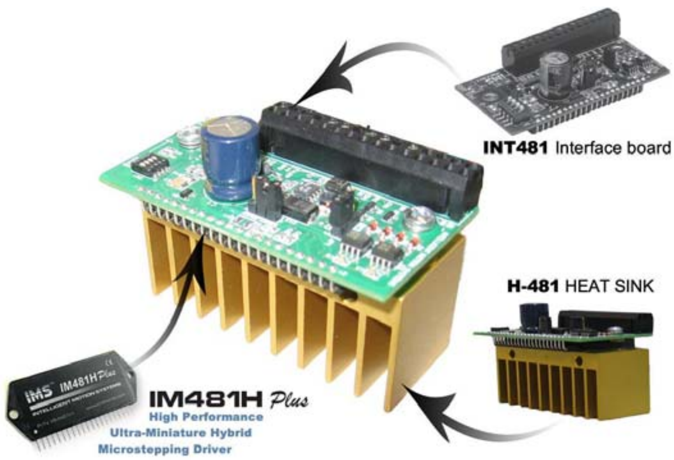


Figure 9.4. Intelligent Motion System IM481H plus

INT-481 Interface Board

The INT-481 is an optional plug-on interface board which can be used with the IM481H PLUS to facilitate testing, or in situations where panel mounting the IM481H PLUS is preferred. The INT-481 contains extra circuitry which includes +5 VDC supply, opto-isolators for step clock, direction, enable and reset, along with extra fault detection circuits, input capacitor, and fault and power LEDs. Wiring is done through a 15 pin screw terminal. A four position dip switch is supplied for microstep resolution selection.

H-481 Heat Sink

The H-481 is a small, optional heat sink which mounts easily to the IM481H PLUS or the INT-481H/ IM481H PLUS com bi nation. Its compact size consumes only 4.3 cubic inches (70.5 cubic cm) of space. All required mounting hard ware is included with the heat sink.

User Interface

User interface was programmed in LabView based software, we have been able to control switching of valve when was necessary and after sensor signalizing changing pump flow direction as well. Changing of frequency during work of pump can easily manage velocity of flow, filling of microplate and thus handle precision analysis.

Macrosampling

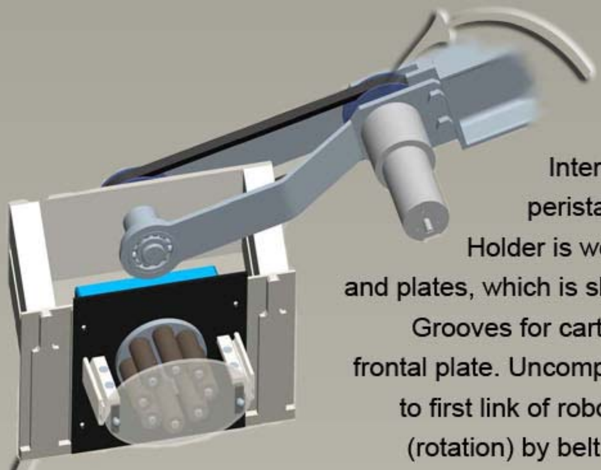
- diaphragm pump Schwarzer Präzision SP200EC-LC (see testing 1)
- Sensor opto-switch HOA1397-1 from Honeywell company
- 100 ml container from borosilicate glass

10 Selection of Solution and Marketing Issues

There were found out many advantages and drawbacks in the both solutions during testing. Solution one is simpler, more universal, modular and has only one actuator which is used in both parts micro and macro sampling as well. On the other hand solution two has been found out quite complicated, can be used only for one sample, no option to switch on the other branch and make sampling from different source. All in all during developing those devices was discovered that solution one of compact cartridge with peristaltic pump is the best option.

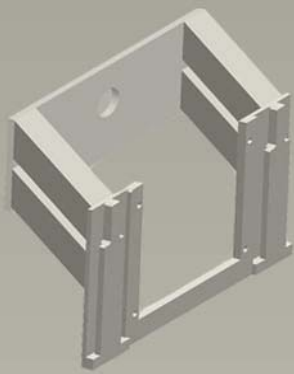
New Sampling Cartridge Original, On-line Operate, Outstanding Product is simply called *SCOOP1* to signify true scoop for new starting age of robotic sampling operations.

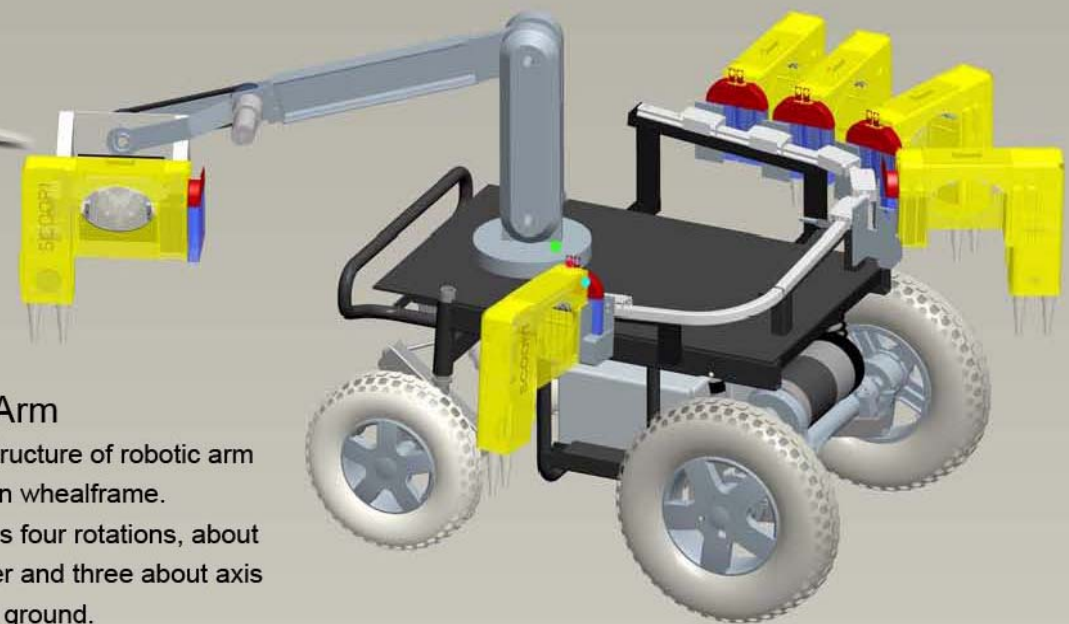
11 Comprehensive Concept Service Robot with SCOOP1



Concept of Interface

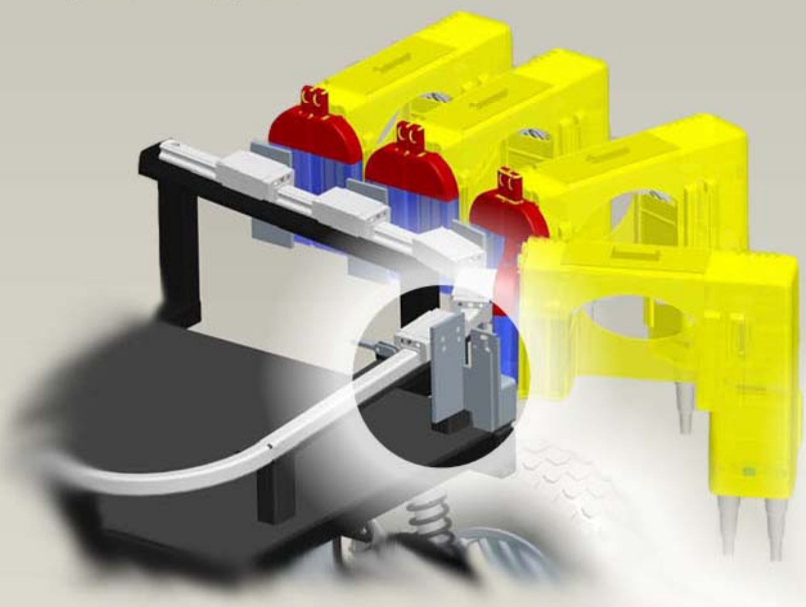
Interface is composed of integrated peristaltic pump and cartridge holder. Holder is weldment from Aluminium tubes and plates, which is shown on right-hand side figure. Grooves for cartridge easy plug-in are milled in frontal plate. Uncomplicated structure of attachment to first link of robot provides one axis orientation (rotation) by belt gear and Brushless DC Motor.





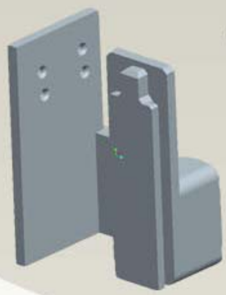
Robotic Arm

Simplified structure of robotic arm is situated on whealframe.
Arm provides four rotations, about base cylinder and three about axis parallel with ground.



Buffer

Simple solution is composed of Straight-Curved Rail which is tilted by 5° to achieve self-moving continuous flow of cartridges Scoop blocked by small mechanical lever with spring.Thus can robot reload and resume working without necessity of any additional actuator. Support of rail is made from rectangular tubes and rods

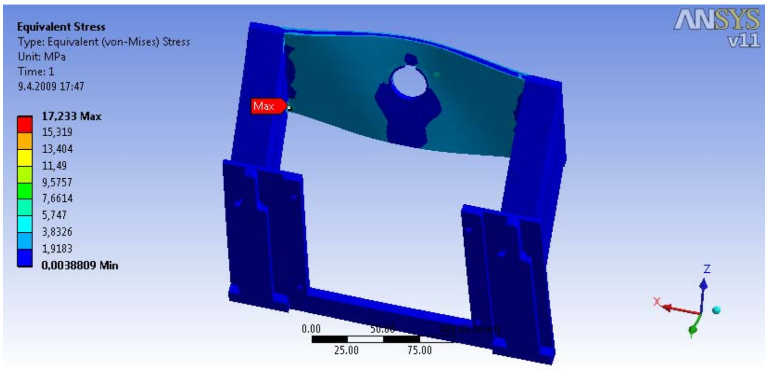


Cartridge Holder

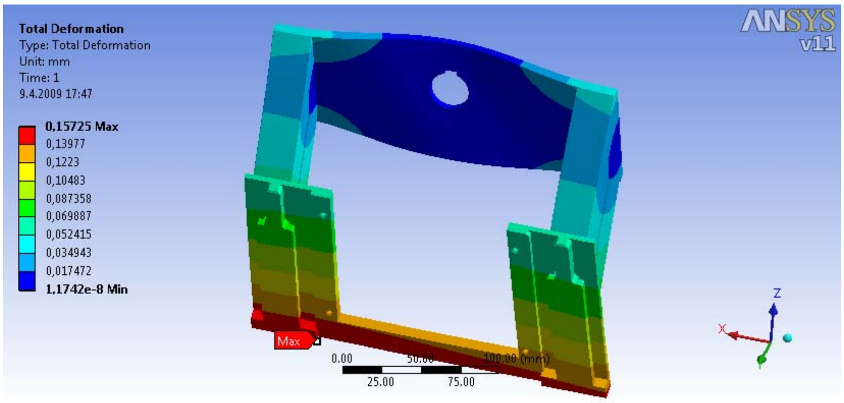
Simple weldment, with groove for plug in of full, ready for exchange, cartridge, is screwed up to slider of Straight-Curved Rail.

12 Weldment Structural Analysis and Shaft Control

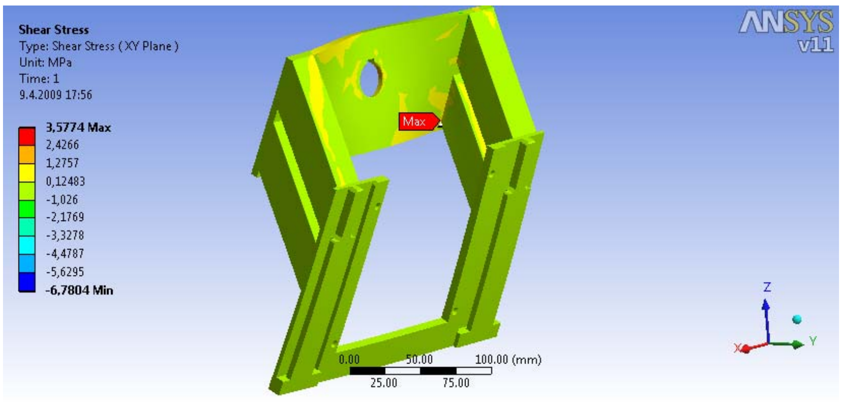
Material of weldment is 42 4400 (Al-Mg1-Si1-Mn) – Avial R_m= 280 MPa. Maximal equivalent stress is in region of stress concentration and it is under lower rectangular tube in area of weld connections with back plate and its value is σ_{vmax}= 17,233 MPa.



Maximal deformation of weldment is in lower part of a front plate on left side, because of the cartridge which is not symmetrically hanged and has not centre of gravity in the middle of the front plate. Thus maximal deformation is δ = 0,157 mm.

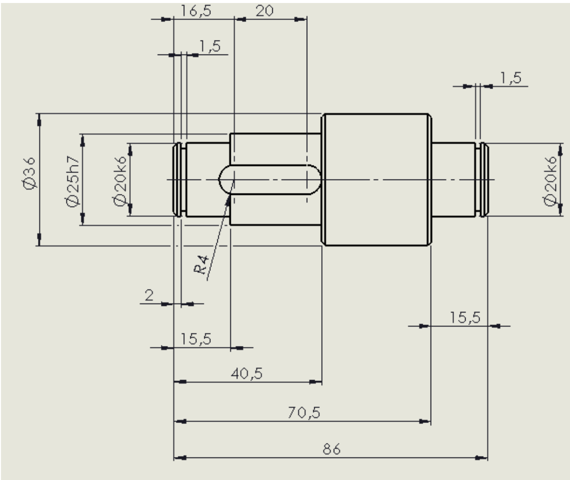


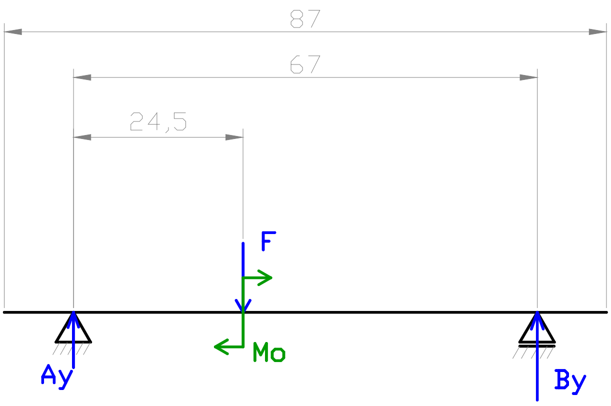
Maximal shear stress is in weld connection of lower rectangular tube with back plate too. Shear stress is taking during maximal load value of τ_{Smax}= 3,6 MPa.



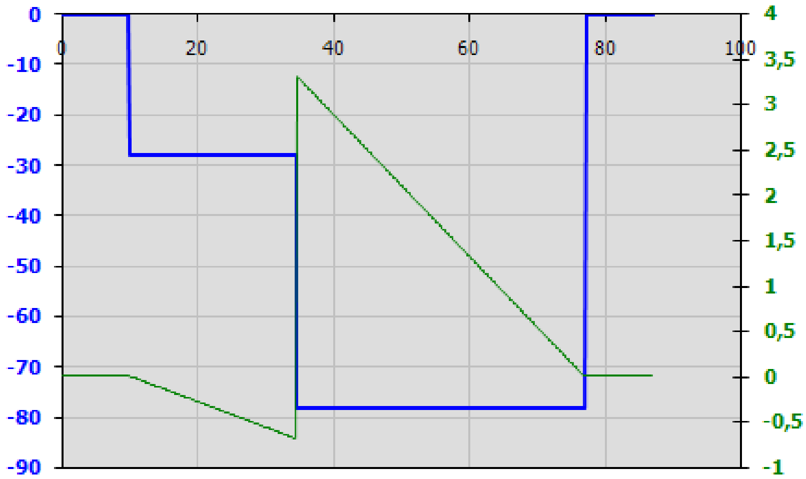
12.1 Control of Shaft

Material 11500





$$M_O = 4\,Nm$$
$$F = 50\,N$$
$$\sigma_{\mathrm{OD}} = 360\,MPa$$
$$l = 0{,}067\,m$$
$$l_1 = 0{,}0245\,m$$
$$l_2 = l_1 - l = 0{,}0425\,m$$
$$\sum Fix = 0 \Rightarrow Ax = 0$$
$$\sum M_{iA} = 0 \Rightarrow$$
$$\Rightarrow B_Y \cdot l - M - F \cdot l_1 = 0$$
$$B_Y = \frac{M + F \cdot l_1}{l} = \frac{4 + 50 \cdot 0{,}0245}{0{,}067}$$
$$\underline{\underline{B_Y = 78\,N}}$$
$$\sum M_{iB} = 0 \Rightarrow$$
$$\Rightarrow -A_Y \cdot l - M + F \cdot l_2 = 0$$
$$A_Y = -\frac{M - F \cdot l_2}{l} = -\frac{4 - 50 \cdot 0{,}0425}{0{,}067}$$
$$A_Y = \underline{\underline{-28\,N}}$$
$$\sum Fiy = 0 \Rightarrow A_Y - F + B_Y = 0\,N$$
$$T_A = A_Y = \underline{\underline{-28\,N}}$$
$$T_{l_1} = A_Y - F = \underline{\underline{-78\,N}}$$
$$T_B = T_{l_1} + B_Y = \underline{\underline{0\,N}}$$



Course of a Force [N]
Course of a Moment [Nm]

$$M^A_{O(0)} = A_y \cdot 0 = 0$$
$$M^A_{O(l_1)} = A_y \cdot l_1$$
$$M^A_{O(l_1)} = -0{,}686\,Nm$$
$$M^B_{O(0)} = B_y \cdot 0 = 0$$
$$M^B_{O(l_2)} = B_y \cdot l_2$$
$$M^B_{O(l_2)} = 3{,}315\,Nm$$
$$M_{O\max} = 3{,}315\,Nm$$

$$\sigma_{o\max} = \frac{M_{O\max}}{W_O} = \frac{3315}{1534} = \underline{\underline{2{,}161\,MPa < \sigma_{\mathrm{Do}}}}$$

$$W_O = \frac{\pi \cdot d_2^{\,3}}{32} = \frac{\pi \cdot 25^3}{32} = 1533{,}981\,mm^3$$

Specified dimensions and material of Shaft are convenient

13 Conclusion - Závěr

In case of unknown contaminated liquid was necessary to determine as universal solution as possible, due to this fact was realized solution in witch can be done variations of sampling and even can be made simple analyses instantaneously in the one fieldwork of the robot. TYGON® R-3603 Laboratory Tubing characterize cheap and fast answer for cleaning and preparing robot for next job, instead of expensive decontamination of device is enough to throw away whole set of tubing and replace it by new one. Thanks to switching mechanism, tubing can be extended in certain distance from whole end effector, which can protect tool from danger liquid or just can make possible sampling in hard accessible places like barrels or holes. Concept of cartridge represents very easy maintenance and good modularity. The dimensions of tool were considered smaller it the beginning, however with decreasing time of sampling, increasing required power of pump, hence proportions has to be bigger as well.

Vzhledem k tomu, že původ a složení kapaliny, která má být testována je neznámé, bylo nezbytně nutné vymyslet řešení co nejuniverzálnější. Na základě této skutečnosti bylo vyhotoveno a vybráno řešení, ve kterém lze provést mnohočetné odběry a dokonce je možné provést okamžitou zevrubnou analýzu přímo na místě. TYGON® R-3603 Laboratorní hadičky představují levnou a rychlou odpověď na znovuuvedení efektoru do původního stavu. Místo drahé a zdlouhavé dekontaminace je lepší vyhodit použité hadičky a nahradit je novým setem. Díky jednoduchému rolovacímu mechanismu, hadičky mohou být prodlouženy do určité vzdálenosti od koncového členu robotu, což ochraňuje samotný efektor od případného poničení nebezpečnou kapalinou. Navíc takto uspořádaná struktura je vhodná pro odběry v hůře dostupných místech, jako jsou barely nebo díry. Celkový koncept kazety představuje jednoduchou údržbu, manipulaci a velmi dobrou modularitu. Rozměry nástroje byly z počátku uvažovány menší, ovšem s rostoucími požadavky na rychlost odběru a možnost odebírat tak velké objemy vzorků, vzrostl také požadavek na výkon akčního členu, tudíž proporce celého mechanismu musely být logicky přehodnoceny a zvětšeny. Celkový návrh aplikace kazety SCOOP1 je vyřešen pouze konceptuálně, jako možná varianta. V reálném stavu je ještě nutné dořešit mnoho otázek z oblasti senzoriky, řízení, a taky samotné konstrukce.

14 Future - Budoucnost

Analysis of liquid in the microplates could not be successful or could signify very rough estimations as mentioned previously. This fact is based on sensors which are not such universal to determined so big range of possible liquids, hence, the biggest challenge for future are sensors. In nowadays are for example optical ring resonator bio/chemical sensors under big interest of scientists and a lot of new technologies in this area can be still discovered [25].

Microplate readers are complex devices contain tools for recognising fluid inside the microplate, which is simply plug in, see reference [26]. These readers are approximately as big as printers in nowadays. Future trends of miniaturisations can give us new opportunity to place these readers directly on the robot or even into the end effector, this option will open big age of online analysis, when samples will not need any laboratory testing and will be determined at 100% during fieldwork and results will be sent by wireless technology in the centre of chemical or fire service unit situated in safety area nearby.

Rozbor kapaliny odebrané do mikro-destičky nemusí být úspěšný, nebo může znázorňovat velmi povrchní odhad, jak bylo již zmíněno. Tato skutečnost je zapříčiněna nedostatečnou universálností senzorů, které jsou v destičkách umístěny. Tyto senzory nejsou schopny rozpoznat tak různorodou škálu možných kapalin, tedy je jasné, že největší výzvou do budoucna je zkoumání senzorů.

Čtečky mikro-destiček jsou komplexní zařízení obsahující nástroje pro určení tekutiny uvnitř destiček, které jsou jednoduše zasunuty dovnitř [26]. Tyto čtečky jsou v dnešní době veliké asi jako domácí tiskárna. Budoucí trendy miniaturizací nám dávají nové možnosti. Při dostatečném zmenšení tohoto zařízení bude možné umístit ho přímo na platformu robota či dokonce do efektoru. Tato možnost otevře éru online analýz, kdy vzorky už nebude nutné nadále dopravovat složitě a zdlouhavě do laboratoří aby byly testovány, budou totiž vyhodnoceny jednoznačně již na místě během terénních prací. Výsledky pak budou poslány bezdrátově do centra zásahové jednotky v bezpečné vzdálenosti od kontaminované oblasti. Budoucnost v této oblasti servisní robotiky je více než zajímavá - je to výzva!

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16 Appendixes

Printed form:

Appendix 1 – Tubing pump MCP-E Ismatec 0,002-230 ml/s

Appendix 2 – The Lee company Pump - DWG – Variable Volume

Appendix 3 – Drawing 2ROBO1ASM0003 Kazeta-SCOOP1

Appendix 5 – Drawing 2ROB01ASM0009 Interface

Appendix 6 – Drawing 2ROB01ASM0017 Efektor s kazetou

Electronic form (on CD enclosed):

Drawing - 2ROBO1ASM0003 Kazeta-SCOOP1.pdf

Drawing - 2ROB01ASM0009 Interface.pdf

Drawing - 2ROB01ASM0017 Efektor s kazetou.pdf

3D model of effector SCOOP1 – asm0017_effector_cartridge

3D model of cartridge SCOOP1 – asm0003_cartridge.asm

3D model of service robot – asm0015_robot_SCOOP1